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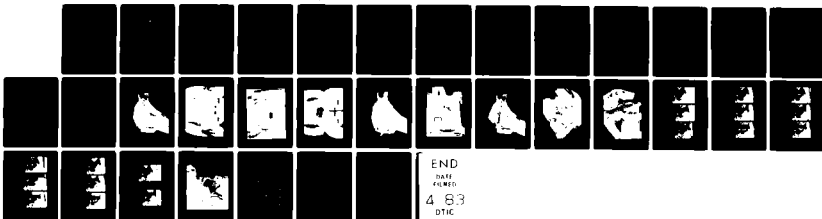
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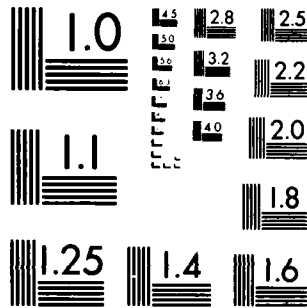
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CENTRIFUGE TESTS OF MODIFICATIONS TO THE MA-2 AIRCREWMAN TORSO HARNESS — PHASE I

Dan Lorch
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974

4 DECEMBER 1982

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TABLE OF CONTENTS

Figure		Page
9	BLU Blue Angels Harness (Side View)	20
10	MA-2 Unmodified - Displacement At $-2G_z$	21
11	MA-2/5 Fifth Strap - Displacement At $-2G_z$	22
12	MA-2/B/5 3-inch Belt With Fifth Strap - Displacement At $-2G_z$	23
13	MA-2/H Attachment Geometry Modification - Displacement At $-2G_z$	24
14	MA-2/V V Belt Over Thighs - Displacement At $-2G_z$	25
15	BLU Blue Angels Harness - Displacement At $-G_z$	26
16	MA-2 (Unmodified) Flat Spin Simulation $-1G_z$, $-1.7G_x$ Inertial Reel Unlocked (Subject 1)	27
17	Change of Z Displacement Between $+1G_z$ and $-2G_z$ (Measured At Helmet Top)	28

LIST OF TABLES

Table		Page
1	CHANGE OF Z DISPLACEMENT (MEASURED AT HELMET TOP) AT $-2G_z$ ACCELERATION	9

SUMMARY

This is Phase I of a two-part Centrifuge Program designed to measure the improvement to Z restraint provided by various modifications to the MA-2 aircrewman torso harness and by several other operational harnesses.

These tests reveal the various factors which influence Z restraint during an aircraft departure from controlled flight and factors influencing X restraint during a flat spin.

RESTRAINT FOR $-G_z$

Because there are so many interdependent factors influencing $-G_z$ restraint it is very difficult to objectively compare various restraint modifications.

In the final analysis we can only determine if a crewman is more likely to restrain himself better in one system more than in another.

The variables affecting restraint are:

- Strap routing;
- Initial strap length;
- Strap material;
- Attachment geometry;
- Ease with which adjustment fittings can be tightened;
- Slippage of fittings under load;
- Crewman's mass;
- Acceleration magnitude, rate of onset, and direction;
- Strap width;
- Thickness of crewman's fat and muscle tissue beneath straps;
- Clothing—thickness and friction properties; and
- Tightness of strap adjustment; which is a function of aircrewman strength, tolerance to discomfort, motivation, and ease of adjustment.

Test results show that the average size aircrewman using a reasonable tight fitting MA-2 harness lap belt can expect to have the top of his helmet displace 9 to 12 cm (4-5 in.) at an acceleration of $-2G_z$.

With the addition of a properly adjusted fifth strap (MA-2/5) or a "V" strap over the thighs (MA-2/V) the average subject's helmet top will displace about 6 to 10 cm (2 to 4 in.); this provides a 2 to 3 cm (1 in.) improvement.

The Z displacement can be reduced an additional 3 cm (1 in.) by providing upper torso restraint similar to the Blue Angels harness. Unfortunately this type of upper restraint usually limits upper torso rotation and is therefore unsuitable for air combat maneuvers unless it is especially designed for this (i.e. the XV Restraint, reference 2).

There are some additional factors which need to be considered when a pilot experiences a departure and is thrown into $-G_z$. The insecurity of hanging in the straps is upsetting enough — head impact with the canopy is certainly a shock — add in the problem of nuts, rivets, washers, pencils, and dirt that fly into his face and you have — DISTRACTION.

The pilot is in no position or condition to get his aircraft quickly under control. The situation gets worse if his inertia reel is unlocked. Any $-G_x$ acceleration will throw him so far forward that he has little chance to regain aircraft control.

However, if a pilot would intentionally put his aircraft through several controlled $-G_z$ "push overs" just before engaging in air combat maneuvers he would not be surprised by these factors when he goes into a departure. He would see that he needs to tighten his straps, and perhaps lower his seat to avoid head impact with the canopy. Or if he intends to use the canopy as an extra brace for his head he can raise himself so that he will be very close to it. This will reduce the impact force during the departure.

RESTRAINT FOR $-G_x$

No system tested was expected to improve the X restraint of the upper torso which is required during a flat spin. Nevertheless, it was considered worthwhile to obtain some photographic coverage of test subjects experiencing a spin. These tests were only conducted at $-2 G_x$; flat spins in the F-14 aircraft can subject the pilot to $-6 G_x$. Under acceleration of this magnitude there are presently only a few possible solutions to keep the crewman's torso from being displaced so far forward that he cannot recover control of his aircraft:

- Fly with a locked inertia reel;
- Modify the inertia reel to lock at less than $-1 G_x$ acceleration of the seat;
- Reduce the maximum possible extension of the inertia reel straps; or
- Utilize a recyclable powered inertia reel which can be easily reached and actuated.

INTRODUCTION

BACKGROUND

Inadequate aircrew restraint has been cited as a factor which has caused the loss of many aircraft after a departure from +G controlled flight (reference 1). The pilot can be displaced so far out of position that he is unable to apply adequate motion to the flight controls to regain stable flight. If he should have to eject he would be in a poor position. This increases the probability of injury.

The Naval Air Development Center (NAVAIRDEVCECN) was assigned the task by the Naval Air Systems Command (NAVAIRSYSCOM) to determine if any simple modifications made to the MA-2 harness would improve $-G_z$ restraint, or if any existing retrofittable harness would be better than the MA-2 harness.

The following restraint systems, and modifications to the MA-2 harness were to be tested:

CODE	HARNESS
MA-2	Integrated torso harness
MA-2/5	Torso harness with "fifth" (negative G) strap
MA-2/B/5	Torso harness with 7.6 cm (3 in.) lap belt and "fifth" strap.
MA-2/H	Torso harness with seat kit attachment geometry modification
MA-2/V	Torso harness with two additional straps over the thighs
BLU	Blue Angels harness
ALPHA	Alpha-Jet harness (Stencel Aircraft Corp.)
MBSC	Martin-Baker simplified combined harness (Martin-Baker Ltd.)
ACES II	USAF restraint

A sequential program of tests were to be conducted by the Naval Air Test Center (NAVAIRTESTCEN), the NAVAIRDEVCECN, and the NAVWPNCEN Parachute Systems Department.

STATIC TESTS AT $-1 G_z$

The NAVAIRTESTCEN would test all systems at $-1 G_z$ with a 50% subject to determine if any looked worthwhile. They would also evaluate the compatibility of the restraints with existing life support equipment.

CENTRIFUGE TESTS - PHASE I: $-2 G_z$ AND FLAT SPIN

The NAVAIRDEVCECN would test several modifications of the MA-2 harness with different subjects at $-2 G_z$. In addition, the systems would be tested in a simulated flat spin in order to document the restraint problems associated with this motion. These would be exploratory tests to determine the photographic coverage and instrumentation to use in the Phase II Centrifuge tests if they were required.

CENTRIFUGE TESTS – PHASE II: DEPARTURE SIMULATION

Only the MA-2 harness and the best two or three systems will be evaluated under conditions simulating a $-2 G_z$ sudden departure. These tests may be replaced by flight tests at the NAVAIRTESTCEN.

PARACHUTE TESTS

The NAVWPNCEN (Parachute Division) will evaluate only the most promising restraint improvements. Tests include; parachute suspension; seat-man separation; physiological evaluation; pool tests; and land and water jump tests.

FLIGHT TESTS

If any system looks worthwhile, it will be flight tested by several pilots at the NAVAIRTESTCEN.

At the completion of the program a decision will be made jointly by the NAVAIRDEVCCEN, the NAVAIRTESTCEN, and the NAVWPNCEN whether to recommend a restraint modification.

PROCEDURE FOR PHASE I CENTRIFUGE TESTS

Three volunteers evaluated the following harnesses in the NAVAIRDEVCCEN centrifuge:

- MA-2 – Integrated torso harness (figure 1);
- MA-2/5 – Torso harness with "fifth" negative G strap (figures 2 and 3);
- MA-2/B/5 – Torso harness with 7.6 cm (3 in.) lap belt and "fifth" strap (figure 4);
- MA-2/H – Torso harness with seat kit attachment geometry modification (figures 5 and 6);
- MA-2/V – Torso harness with a "V" strap over the thighs (figure 7 and 8);
- BLU/T – Blue Angel harness with tight torso straps (figure 9); and the
- BLU/L – Blue Angel harness with loose torso straps.

Since the Blue Angels harness is known to be very good for $-G_z$ restraint, it was tested to determine the minimum expected Z displacement.

Each test subject wore a helmet, tee shirt, shorts, and boots. A loose backup safety belt was always used in case the main restraint failed.

Test subjects were instrumented for blood pressure, EKG, and Doppler blood flow to the head. Each restraint was first evaluated at $-1 G_z$ with an unlocked inertia reel. The gondola was pitched forward so the subject experienced $-1 G_x$ first (inertia reel locked). The time for G onset was low (about 3 sec). The same procedure was used at $-2 G$. Still photographs (35 mm) and movies (16 mm) were taken of the subject's side view.

For the simulated flat spin (with unlocked inertia reel) the subject experienced $-G_x$ for 5 sec, then a pitch oscillation of ± 30 degrees was applied at a rate of 1 cycle per 8 sec for 5 cycles. Still photos were taken when the subject experienced $-1 G_z$ and $-1.73 G_x$ (figure 16).

All measurements were scaled from photographs similar to those shown by figures 10 through 15.

Parallax compensation for photographic measurements were made by photographing a metric grid located at the center line of the seat. A print of this grid was made of clear plastic and was then used on top of the displacement photographs.

All prints were carefully enlarged by maintaining a fixed distance between two reference targets on the ejection seat.

DISCUSSION

Although these tests were not extensive enough to provide a good statistical sampling, nevertheless - some important facts became clear; several factors besides strap routing have a greater influence on restraint required to prevent loss of aircraft control. These factors are:

- How tight the straps are tightened;
- Thickness of fat and muscle tissue beneath straps;
- Crewman's mass;
- Ease of strap adjustment;
- Slack in the inertia reel;
- Initial position of the crewman relative to the canopy; and
- Crewman sitting height

These test results confirm those made by the NAVAIRTESTCEN when they initially evaluated the MA-2 harness in 1978. The following quotes are from the report (reference 1):

"... even a good lap belt restraint system (i.e. zero off-seat displacement) will result in displacement of between 1.75 cm and 5.87 cm (0.69 in. and 2.31 in.) ... This amount of stretch of and by itself could permit aircrew contact with the canopy in many aircraft, even proper restraint sizing and proper tightening of restraint subsystems, and could result in degradation of aircrew performance".

They recommended a restraint of the torso in two parts;

- "Fixing" the buttocks of the crewman firmly to the seat pan; and
- Control of the degree of torso stretch.

Since all of the modifications tested (except for the Blue Angels restraint) were attempts only to improve lower torso restraint it was expected that the best that could be done at $-1 G_z$ was to restrain head displacement between 3 cm to 6 cm; at $-2 G_z$ the displacement was expected to be greater.

Preliminary tests at the NAVAIRTESTCEN have shown that when the subject adjusts his restraint straps ten different times, the range of his head displacement at $-1 G_z$ is about ± 3 cm on either side of a mean displacement. Variation of this magnitude calls for a large number of displacement measurements to obtain a statistical base. Since Centrifuge time was limited and these Phase I tests were exploratory in nature it was not feasible to obtain a large number of measurements. Therefore the data shown in table 1 and in figure 17 can only be used to obtain a "feeling" for the ranking of restraint modifications. Statistical data will eventually be made available from the NAVAIRTESTCEN tests and these will reveal the mean displacements expected from the MA-2 harness and from one or two of the better restraints.

TABLE I - CHANGE OF Z DISPLACEMENT (MEASURED AT
HELMET TOP AT - 2 G_z ACCELERATION

TEST SUBJECT			
	S1	S2	S3
WEIGHT	56.9 kg (125 lbs.)	81.9 kg (180 lbs.)	97.7 kg (215 lbs.)
SITTING HEIGHT (no helmet)	86.8 cm (34.2 in.)	94.0 cm (37.0 in.)	97.5 cm (38.4 in.)
RESTRAINT	DISPLACEMENT		
MA-2	9 cm (3.5 in.)	11 cm (4.3 in.)	12 cm (4.7 in.)
MA-2/5	7 cm (2.7 in.)	10 cm (3.9 in.)	12 cm (4.7 in.)
MA-2/V	5 cm (1.9 in.)	8 cm (3.1 in.)	10 cm (3.9 in.)
MA-2/H	10 cm (3.9 in.)	11 cm (4.3 in.)	12 cm (4.7 in.)
MA-2/B/5	8 cm (3.1 in.)	12 cm (4.7 in.)	11 cm (4.3 in.)
BLU/T		7 cm (2.7 in.)	
BLU/L		8 cm (3.1 in.)	

Table I and figure 17 show the results of the Centrifuge tests. It can be seen that except for MA-2/B/5 the large subject (S3) was displaced the most, followed by the medium size subject (S2), and then the small subject (S1). This is to be expected because of the increased force on the straps and the larger initial torso length. The discrepancy for S2 with the MA-2/B/5 was due to poor adjustment of the 3 - in. lap belt; the fittings were difficult to tighten. This is also the reason that the results of the Blue Angels harness showed no large reduction in displacement. When it is properly tightened it should have restricted Z displacement to less than 4 cm.

The best harness of this series which restricts Z displacement is the Blue Angels harness (BLU/T), followed by the MA-2/V, then the MA-2/5. Unfortunately the good feature of the upper torso restraint on the Blue Angel's harness also restricts torso rotation, and this is unacceptable for an air combat harness.

Since the available Blue Angel harness fitted only subject 2 no tests were conducted with subjects 1 and 3 in this harness.

AVERAGE Z DISPLACEMENT AT - 2 G_z

With a fairly tight lap belt, an aircrewman can expect between 9 to 12 cm (3.5 to 4.7 in.) of Z displacement at - 2 G_z (figure 17). Therefore if the aircrewman sits so that his head is closer than "a fist between his helmet and canopy" his head can be expected to strike the canopy during a departure.

HOW MUCH Z DISPLACEMENT CAN BE TOLERATED?

At what displacement will a pilot no longer be able to regain aircraft control? This is a hard question to answer, but the 9 to 12 cm Z displacement should not by itself prevent recovery. If, however, this is coupled with some X displacement and acceleration, plus the distraction from hitting the canopy, then the pilot could be in real trouble.

WHAT CAN BE DONE TO IMPROVE - G_z RESTRAINT?

Three cm of displacement can be removed by tightening the lap belt until it is uncomfortable

The addition of a fifth strap (MA-2/5) or a "V" strap over the thighs (MA-2/V) will reduce Z displacement by about 2 cm. However, either addition increases the number of straps to disconnect for an emergency egress.

If a pilot normally flies "loose", will the addition of a fifth strap or "V" strap impel him to tighten his restraint? If the answer is yes, then it may be practical to incorporate either of these modifications. If not, then they would be a useless encumbrance.

The most effective reduction in displacement (3 cm) can be attained with upper torso restraint, but there is a tradeoff; this could restrict the ability of the pilot to turn around during air combat maneuvers unless it is properly designed.

Some pilots may find it convenient to use the canopy as an extra brace for their head. By flying close to the canopy the impact force can be reduced; the head will not have much chance to build up speed before contact. This technique may not be practical with some pilots and some aircraft. However, each pilot should explore - G_z in a controlled situation before being thrown into it during a departure.

The best immediate solution is to make pilots aware of their particular restraint problem by having them practice controlled - G_z push overs at - 1 G_z and - 2 G_z . This will convince them of the necessity to both lower their seat and to tighten their lap belt prior to engaging in air combat maneuvers.

WHAT CAN BE DONE ABOUT - G_x RESTRAINT DURING A FLAT SPIN?

Figure 16 shows each of the three test subjects being thrown forward with an acceleration of -1.7 G_x and -1.0 G_z . The inertia reel was unlocked to represent the way pilots fly air combat maneuvers so they can have the mobility to look aft for the trail of incoming rockets. If the aircraft should experience a departure and enter into a flat spin, the acceleration could get as high as - 6 G_x (F-14 aircraft). It is just about impossible for the pilot to recover once he is at the full extension of the inertia reel straps.

Only a few practical solutions are available to correct this problem in existing aircraft:

- The pilot can fly with his inertia reel locked as he engages in air combat maneuvers;
- The inertia reel travel can be shortened;

- The inertia reel can be modified to lock automatically at less than $-1 G_x$ as sensed by the seat; or
- A recyclable powered inertia reel could be employed which would forceably pull him back into his seat.

RECOMMENDATIONS

1. How effectively would pilots use a "V" strap or fifth strap? This question should be answered with a short series of $-1 G_z$ tests at the NAVAIRTESTCEN where pilots would adjust their straps and be inverted several times on the static test fixture. Displacements with the MA-2, MA-2/V, and MA-2/5 should be compared statistically.
2. The NAVAIRDEVCEEN should develop a harness incorporating both upper and lower torso restraint, yet still permit rotational mobility.
3. The inertia reel should be modified to automatically lock at less than $-1 G_x$ or $-1 G_z$ seat acceleration.

REFERENCES

1. Bason, R., Lt, USN, and Etheredge, J., HM2, USN, "Aircrew Personnel Restraint Subsystems Definition of Deficiencies and Requirements," Naval Air Test Center Technical Report SY-28R-78, 24 August 1978.
2. Lorch, D., "Development of the XV Aircrewman Restraint Harness," Naval Air Development Center Report No. NADC-82108-60.

ACKNOWLEDMENTS

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Figure 1. MA-2 Harness Unmodified



Figure 2. MA-2/5 Torso Harness With Fifth Strap

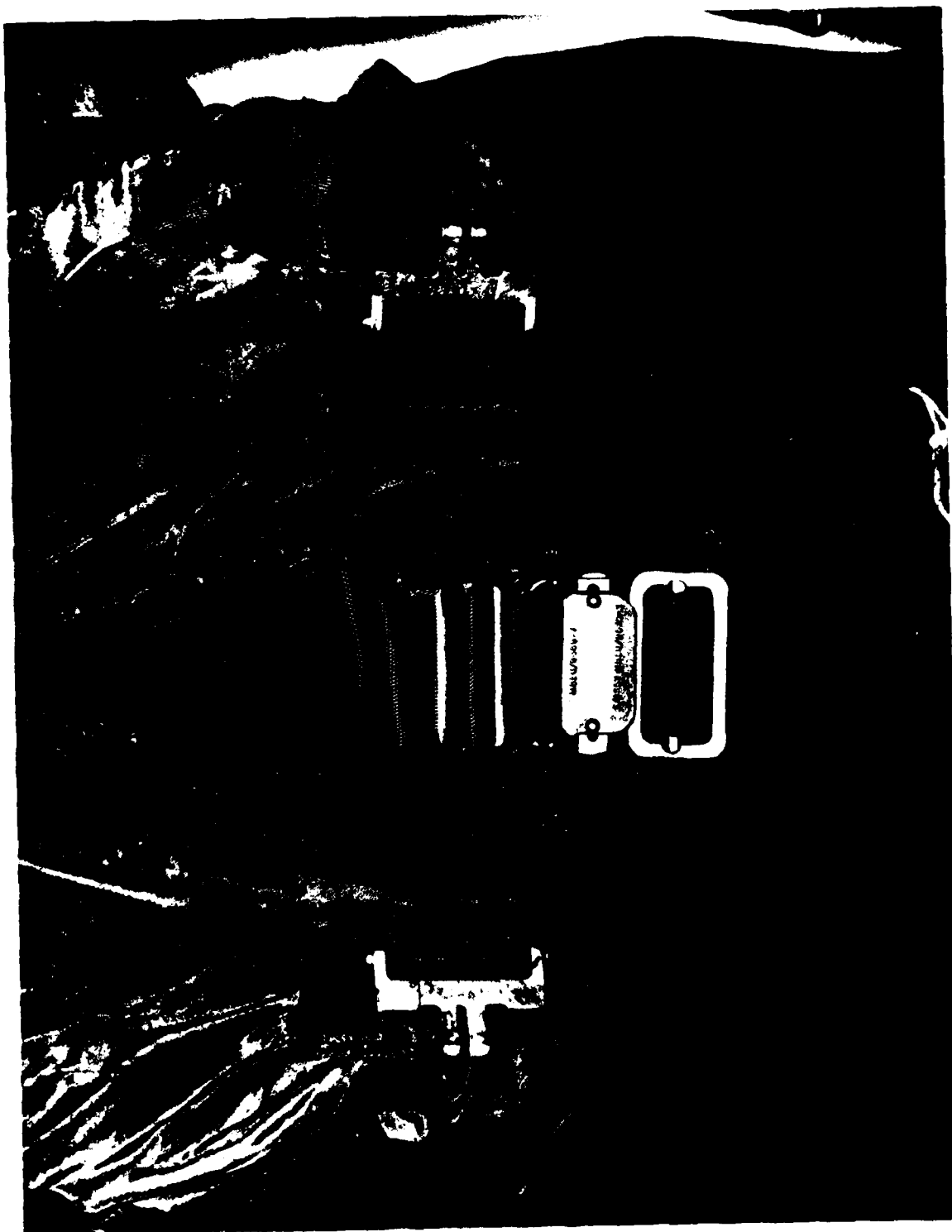


Figure 3. MA-2/5 Fifth Strap (Close-up)

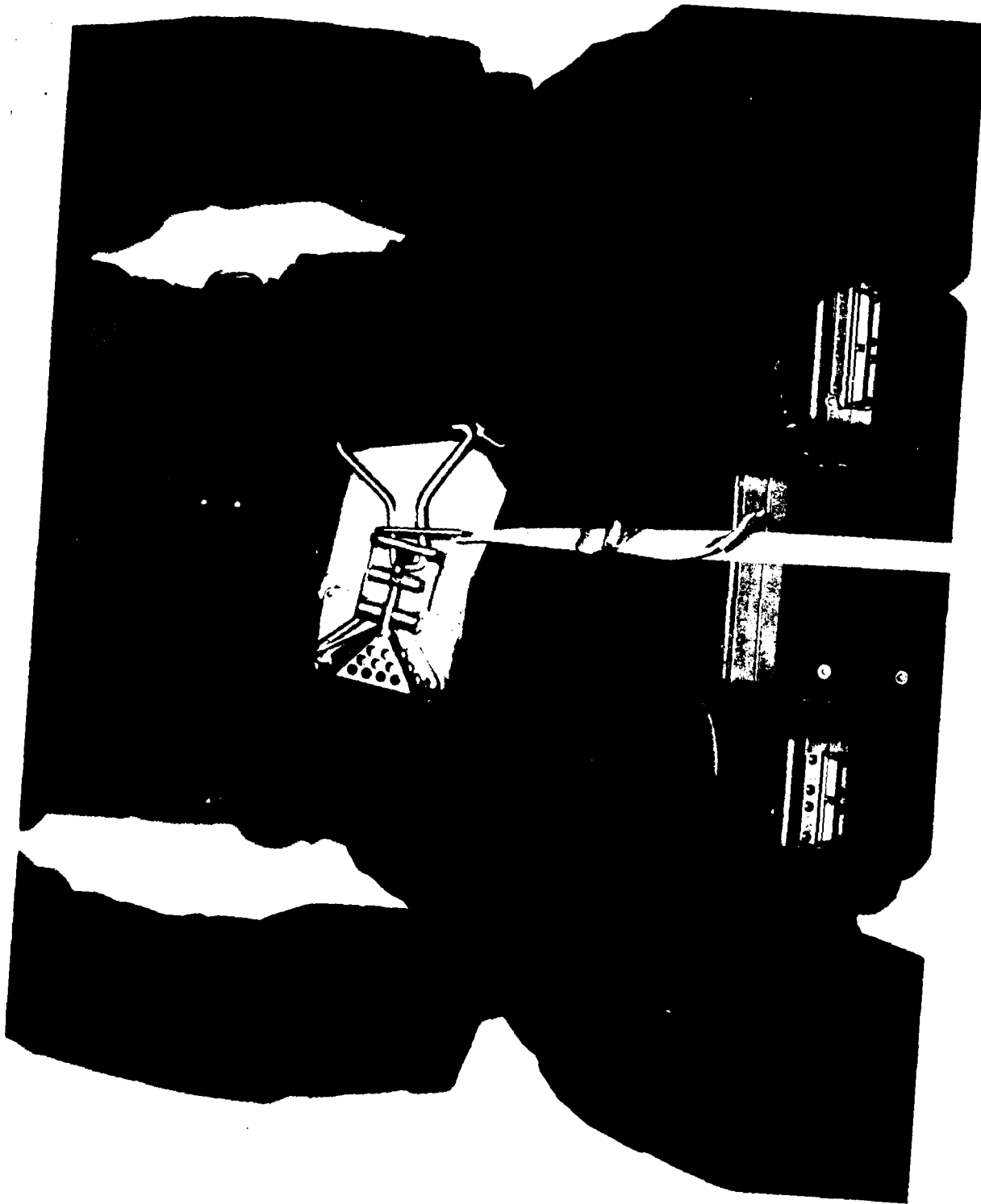


Figure 4. MA-2/B/5 3-Inch Wide Lap Belt With Fifth Strap (Negative G Strap)



Figure 5. MA-2/H Attachment Geometry Modification

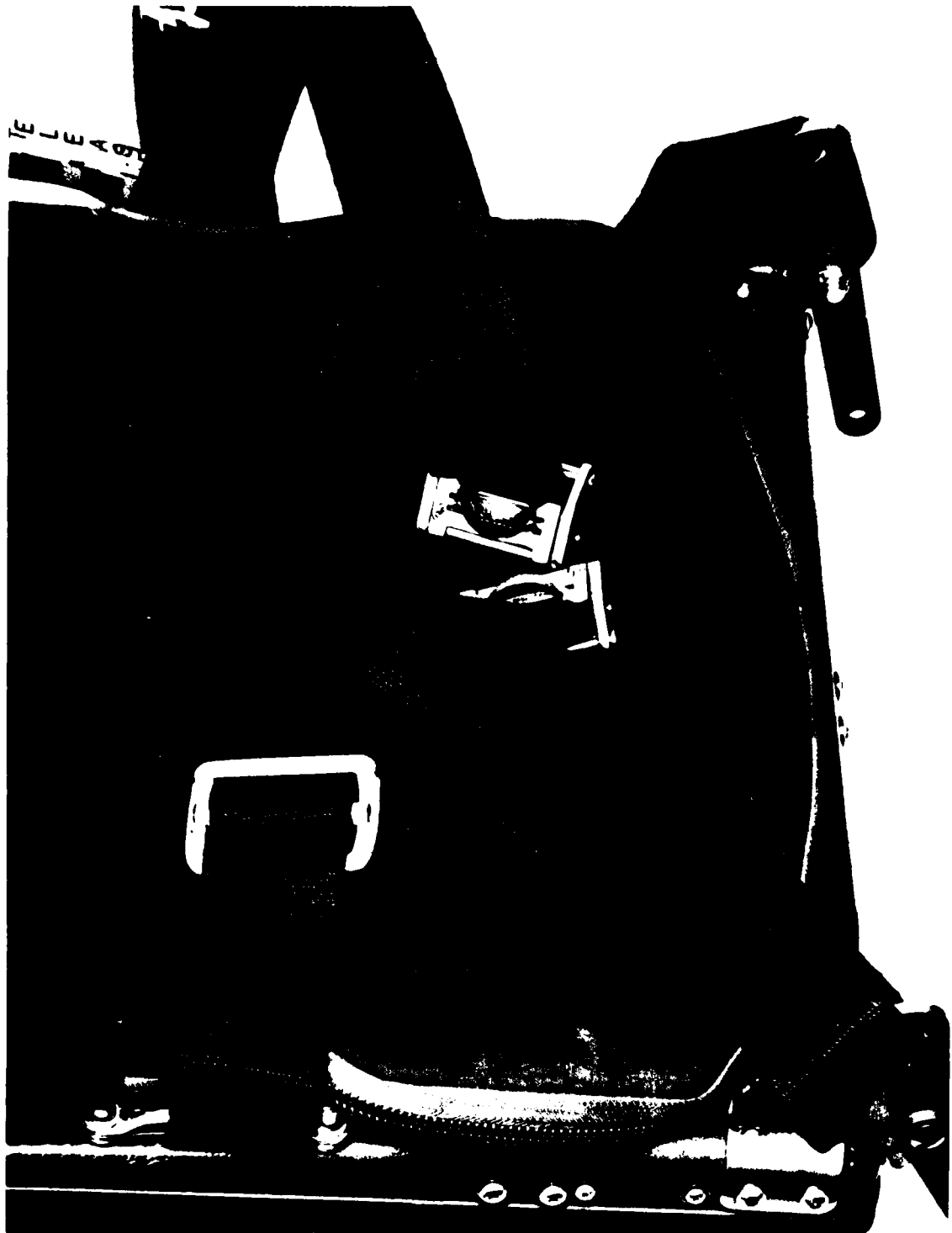


Figure 6. MA-2/H Attachment Geometry Modification (Close-Up)



Figure 7. MA-2/V Harness With V Belt Over Thighs (Side View)

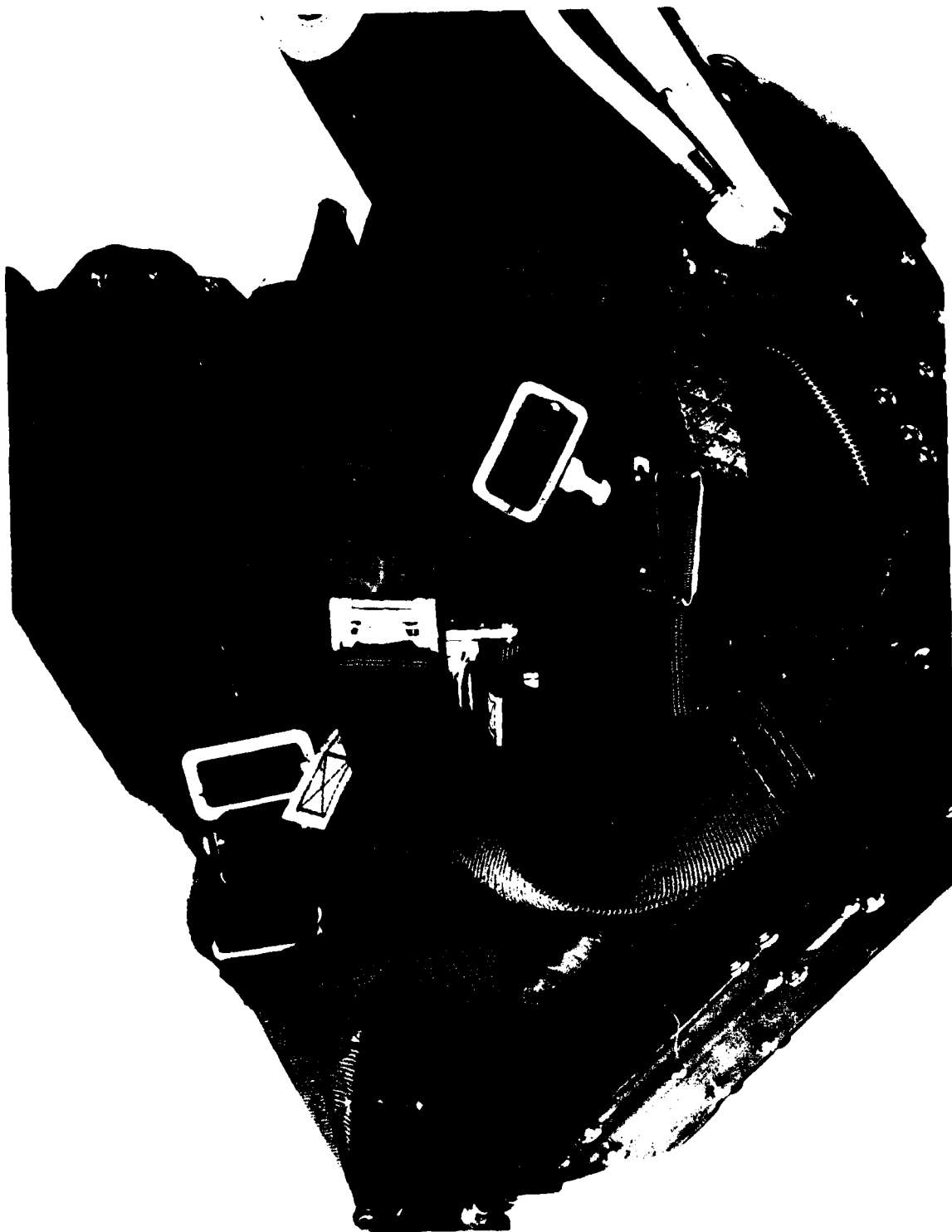


Figure 8. MA-2/V V Belt (Close-Up)

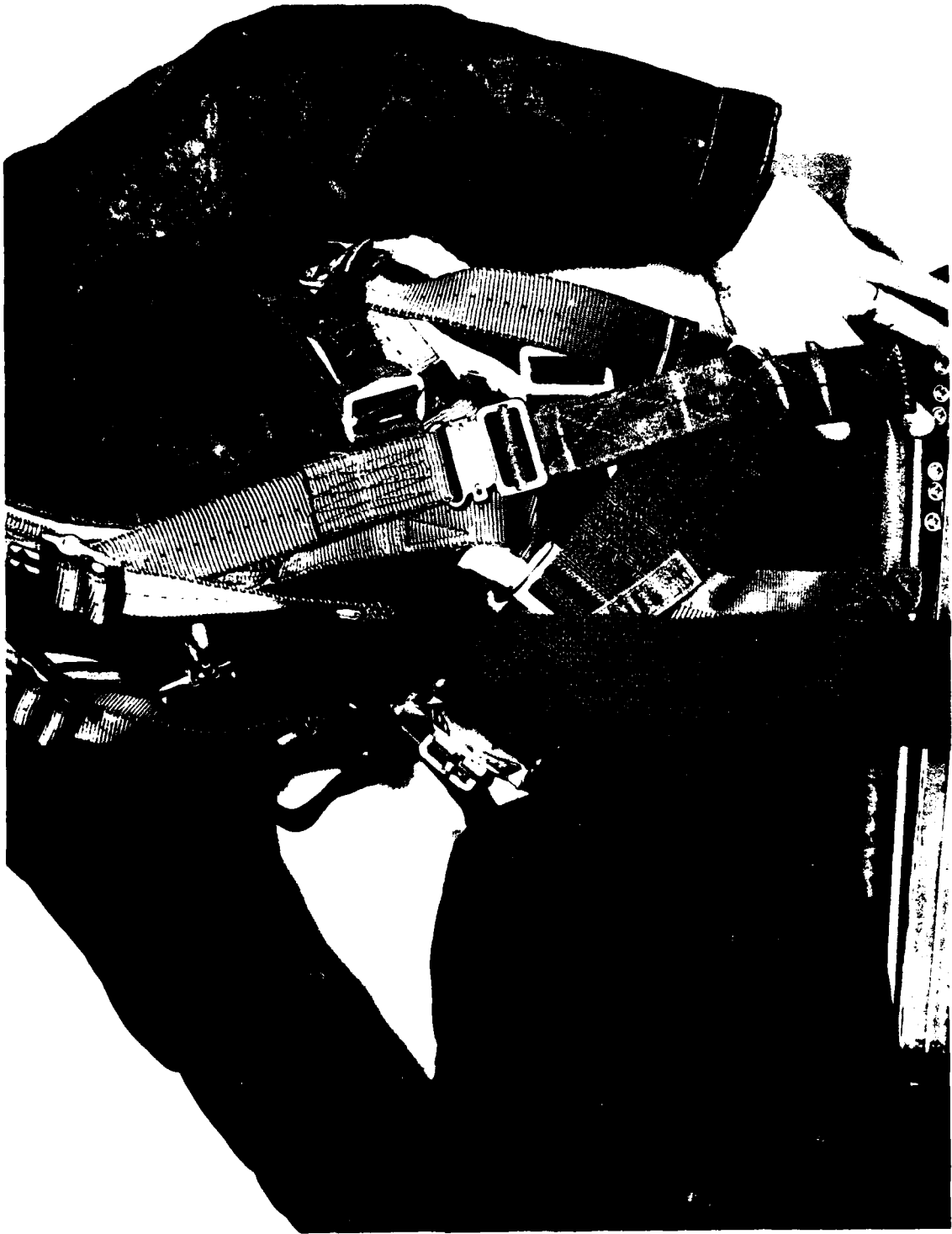
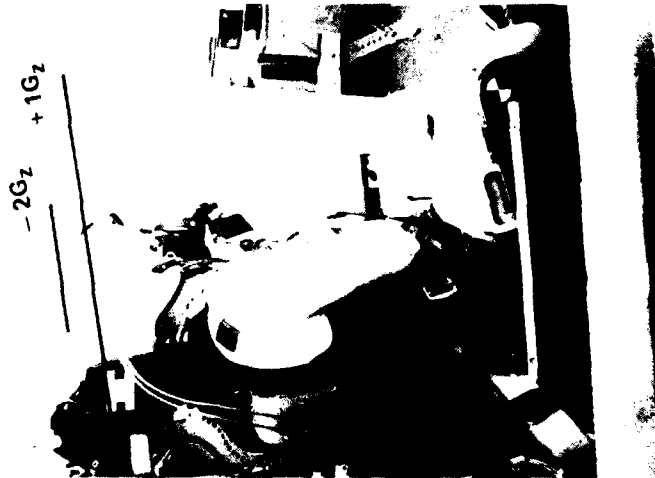
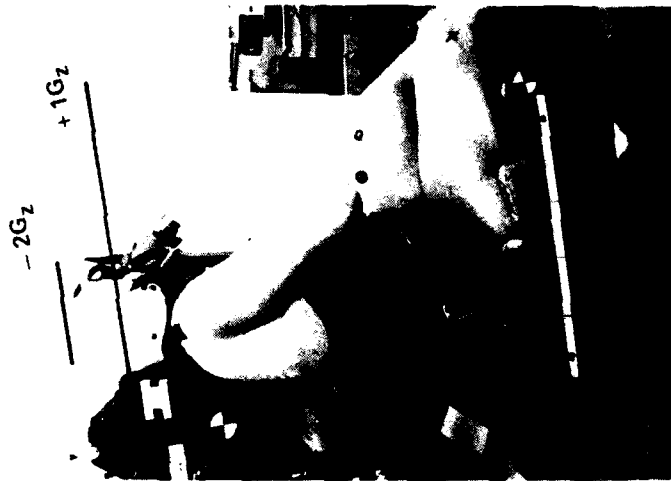


Figure 9. BLU Blue Angels Harness (Side-View)



SUBJECT 1



SUBJECT 2



SUBJECT 3

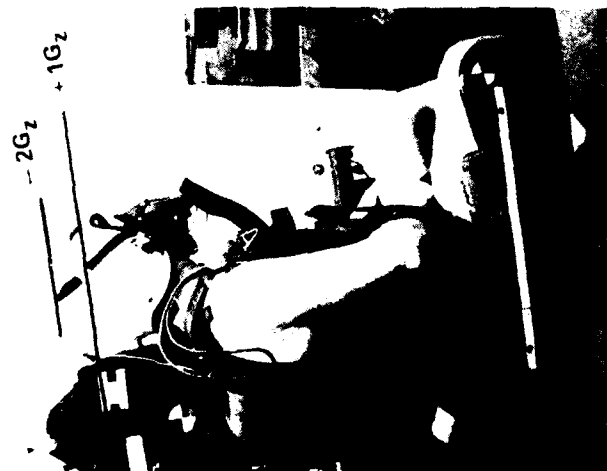
Figure 10. MA-2 Unmodified - Displacement At $-2G_z$



SUBJECT 3



SUBJECT 2



SUBJECT 1

Figure 11. MA-2/5 Fifth Strap - Displacement At $-2G_z$



SUBJECT 3



SUBJECT 2



SUBJECT 1

Figure 12. MA-2/B/5 3-Inch Belt With Fifth Strap -- Displacement At $-2 G_z$



SUBJECT 3



SUBJECT 2



SUBJECT 1

Figure 13. MA-2/H Attachment Geometry Modification - Displacement At $-2G_z$

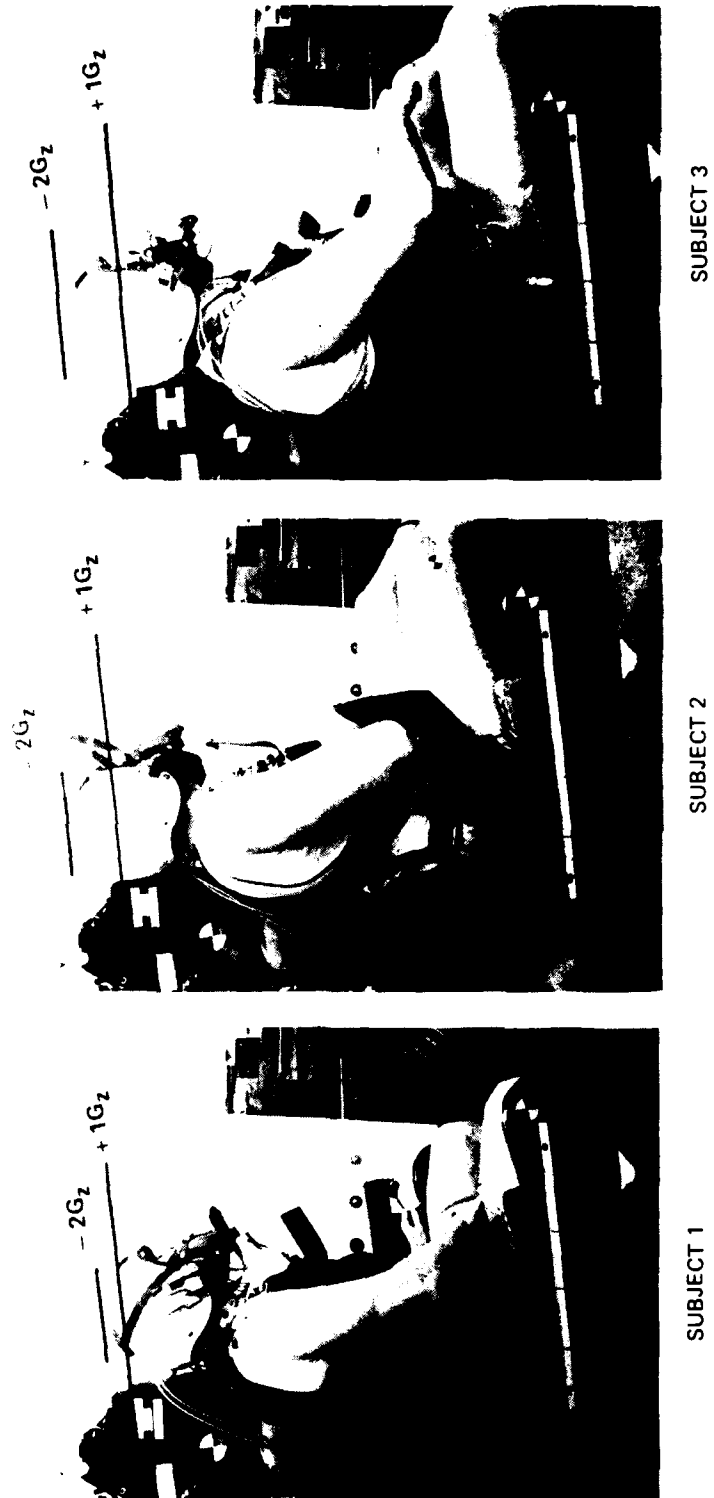


Figure 14. MA-2/V V Belt Over Thighs - Displacement At $-2G_z$



SUBJECT 2
BLU/L LOOSE TORSO STRAPS



SUBJECT 1
BLU/T TIGHT TORSO STRAPS

Figure 15. BLU Blue Angels Harness - Displacement At $-2G_z$



Figure 16. MA-2 (Unmodified) Flat Spin Simulation - $1G_z$, $-1.7G_x$ Inertia Reel Unlocked (Subject 1)

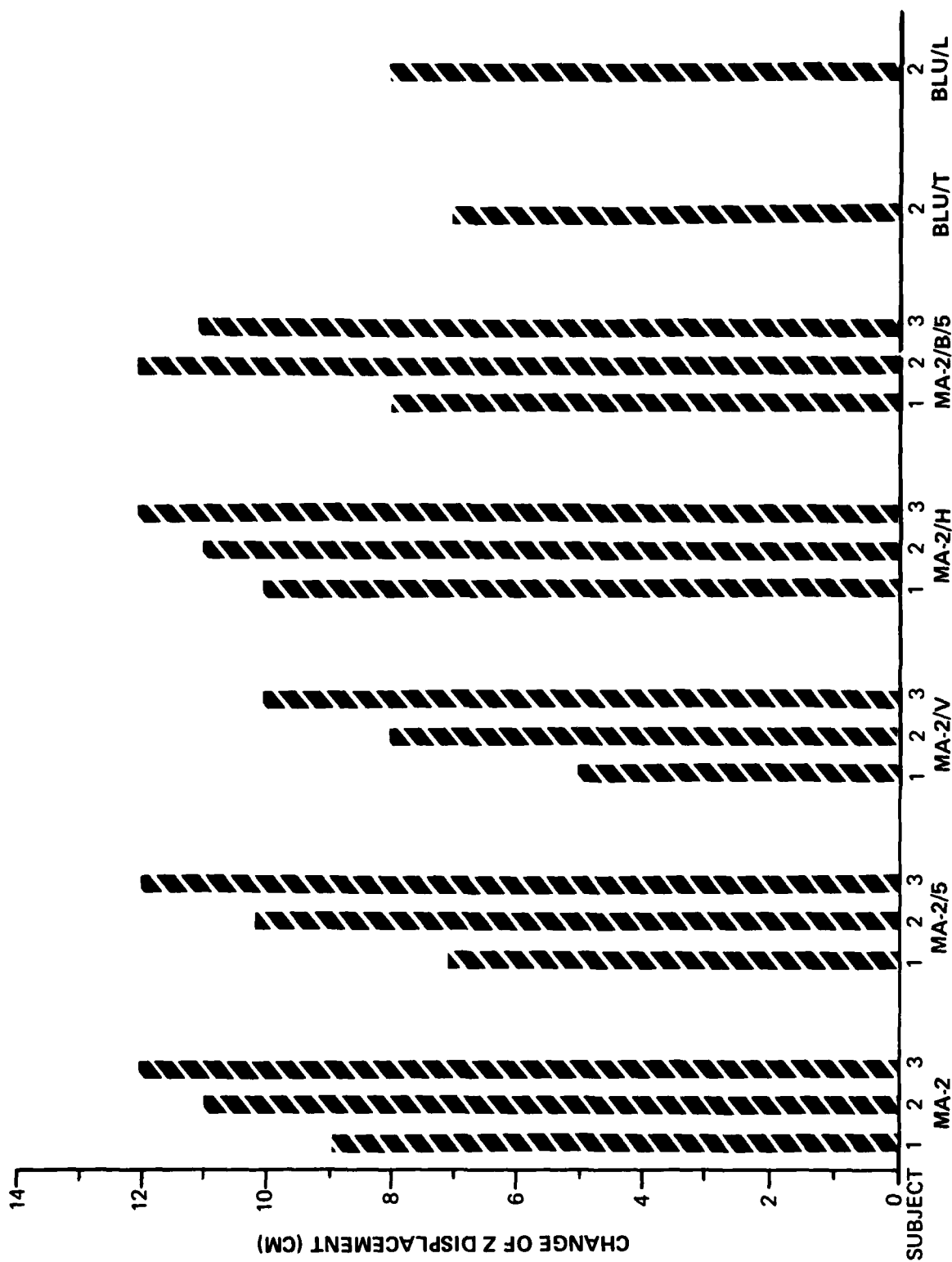


Figure 17. Change of Z Displacement Between + 1 G_z and -2 G_z (Measured At Helmet Top)

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